Satellite-Derived Atmospheric Motion Vectors: Current and Future Products

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Topics

- Benefits of satellite-derived winds: Why do we generate them?
- Physical Description: Estimating Atmospheric Motion from Satellite Imagery
  - » Algorithm Description and Challenges
  - » Today's Atmospheric Motion Vector Products
- Preparing for the GOES-R Advanced Baseline Imager (ABI)
  - » Leveraging the new capabilities of the GOES-R ABI
  - » Algorithm Development Activities (GOES-R AWG Program)
- Future plans

Benefits of Satellite-Derived Winds:
Why do we generate them?...

- They provide vital tropospheric wind information over expansive regions of the earth devoid of in-situ wind observations that include oceans, polar regions, and Southern Hemisphere land masses.

- Continue to be an important observational input into operational NWP data assimilation systems
  - » Their use has been demonstrated to improved numerical weather prediction forecasts including tropical cyclones

- Provide wind observations for NWS field forecasters (via AWIPS)

- Provide wind observations for FAA flight route planners

Physical Description:
Estimating Atmospheric Motion from Satellite Imagery

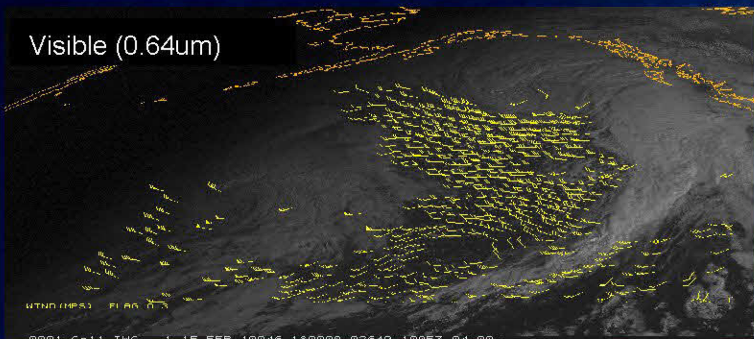
- **Atmospheric motion is determined through the tracking of features in time.**
  - » Features can be clouds, or in the case of clear-sky conditions, moisture gradients.
    - – The choice of spectral band will determine the intended target (cloud or clear-sky moisture gradient) and location (low, mid, upper troposphere) in the atmosphere.
  - » Assumption: Clouds or water vapor features are conservative, passive tracers of the wind field
    - – A reasonable assumption in many instances that results in feature tracking solutions that serve as a good proxy to the horizontal wind field
    - – Not always a good assumption as changes in shapes and/or radiative characteristics of clouds or water vapor features can lead to errors in derived wind estimates.
    - – Quality control important!

Today's Operational GOES Atmospheric Motion Wind Products

The choice of spectral band will determine the intended target (*cloud or clear-sky moisture gradient*) and location (*low, mid, upper troposphere*) in the atmosphere.

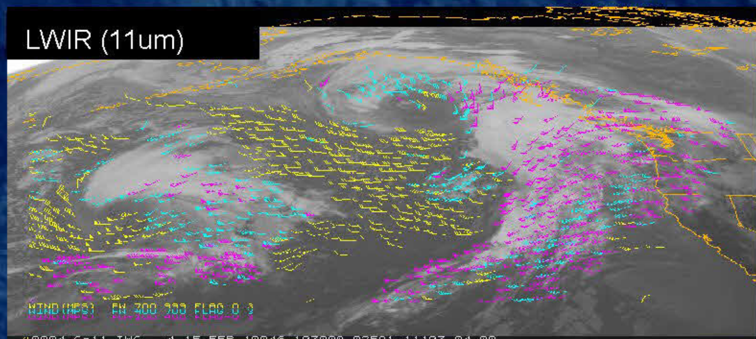
Visible Cloud-drift Winds

- Daytime, Lower troposphere



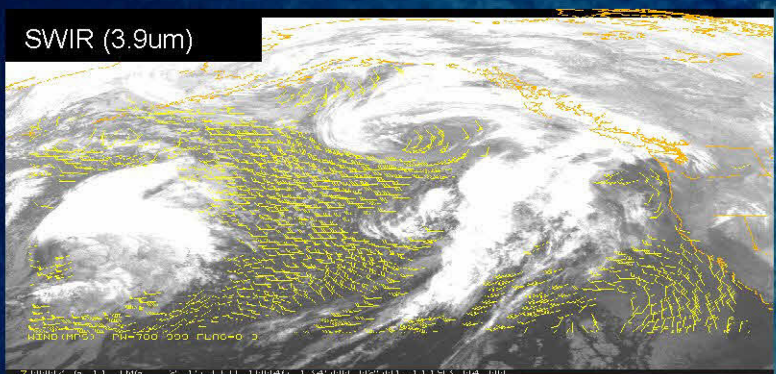
Long-wave IR Cloud-drift Winds

- Day and night; Lower, mid, and upper troposphere



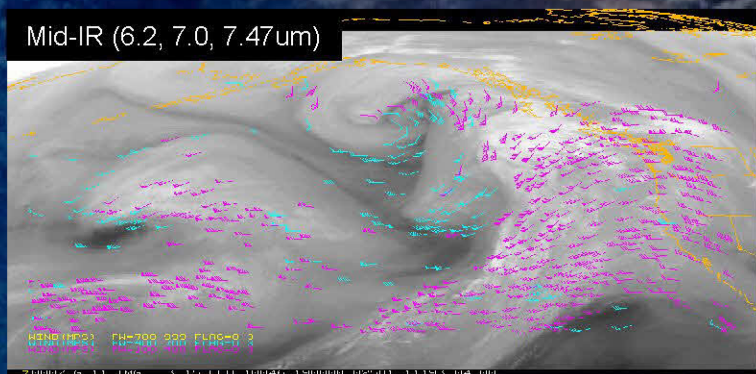
Short-wave IR Cloud-drift Winds

- Night-time, Lower troposphere



Water Vapor Winds

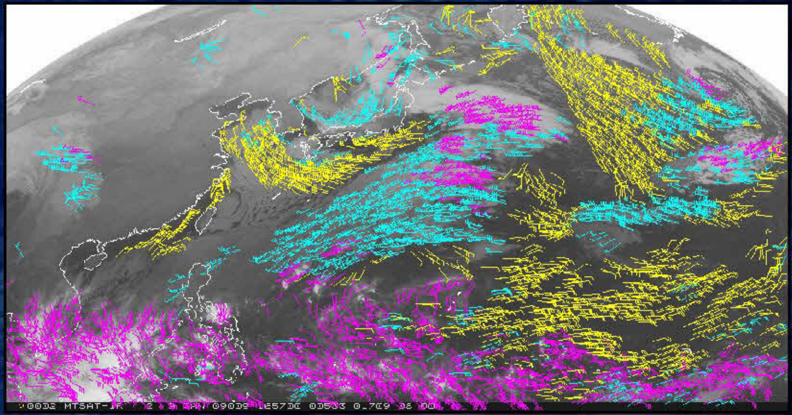
- Cloud-top and Clear-sky; Mid and Upper troposphere)



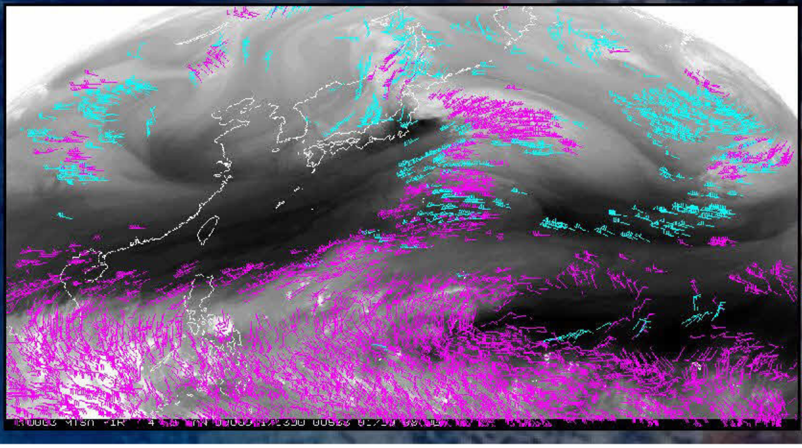
MTSAT Winds Generated Operationally at NESDIS

- The capability to derived winds from the Japanese Meteorological Agency's (JMA) MTSAT satellite has been added to the operational winds processing software and successfully transitioned to operations.
- Product distributed over AWIPS
  - For NWS Western Pacific forecast offices

MTSAT-1R *cloud-drift winds* derived from the long-wave (11um) infrared channel at 18 UTC on 09 Jan 2009.



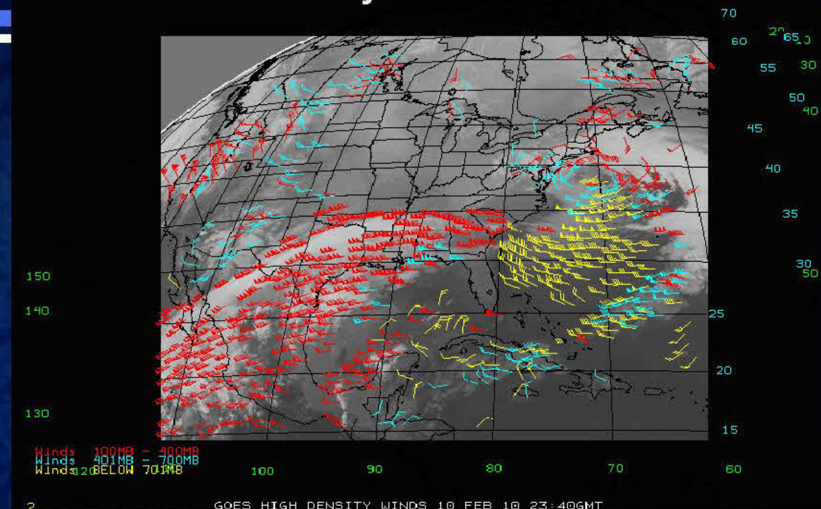
MTSAT-1R *water vapor winds* derived from the mid-wave (6.7um) channel at 18 UTC on 09 Jan 2009



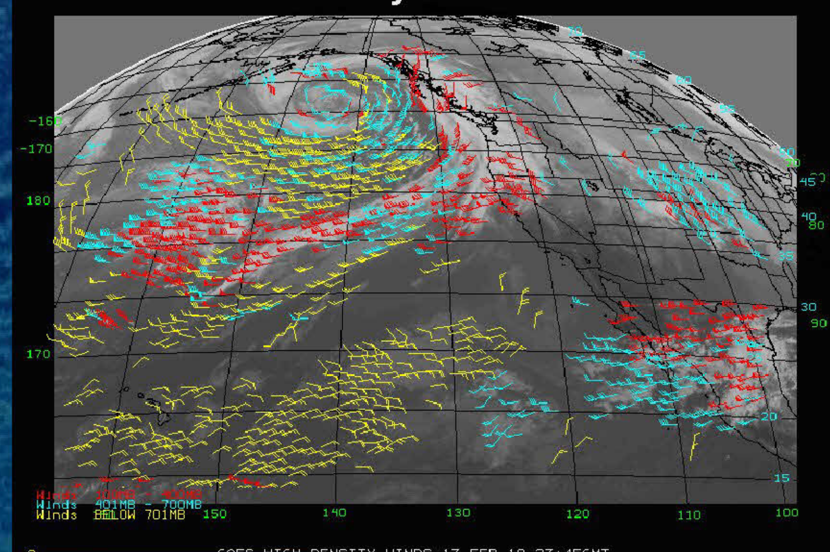
Experimental Hourly GOES Wind Products

- Working to improve refresh rate of current operational GOES wind products from 3-hourly to hourly
- Provide a more time continuous source of satellite wind observations for
  - » Emerging operational 4D-VAR NWP data assimilation systems
  - » AWIPS
- Potential for significant and positive impacts on NWP forecast accuracy

GOES-12 Hourly Cloud-drift Winds

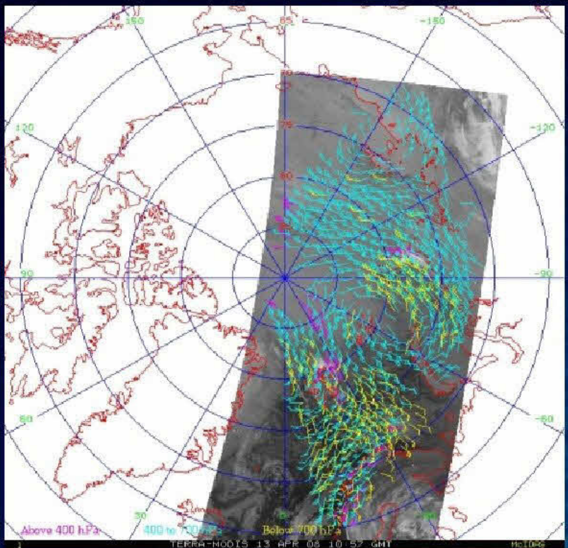


GOES-11 Hourly Cloud-drift Winds

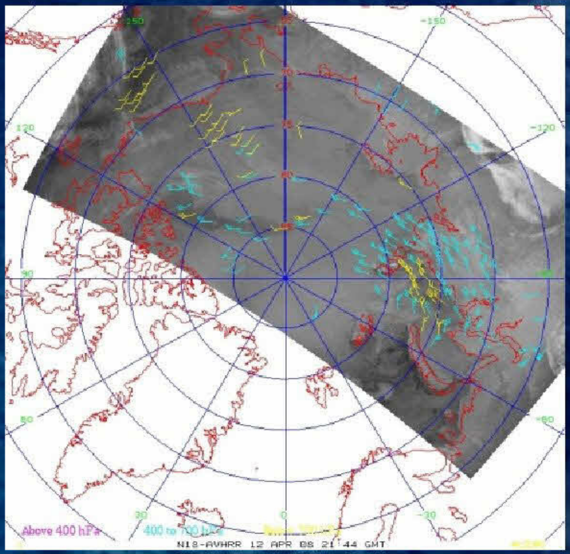


Today's Operational Polar Atmospheric Motion Wind Products

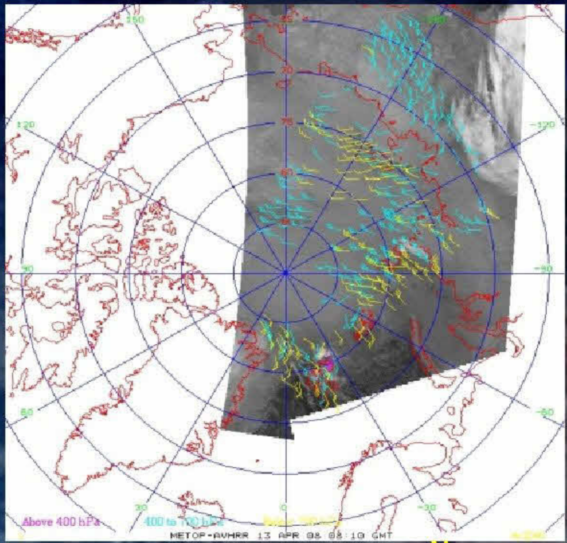
Terra/Aqua MODIS Winds

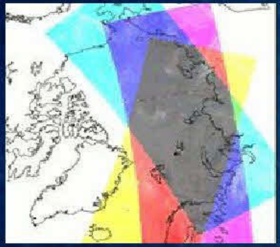


NOAA-AVHRR GAC Winds



METOP-AVHRR Winds





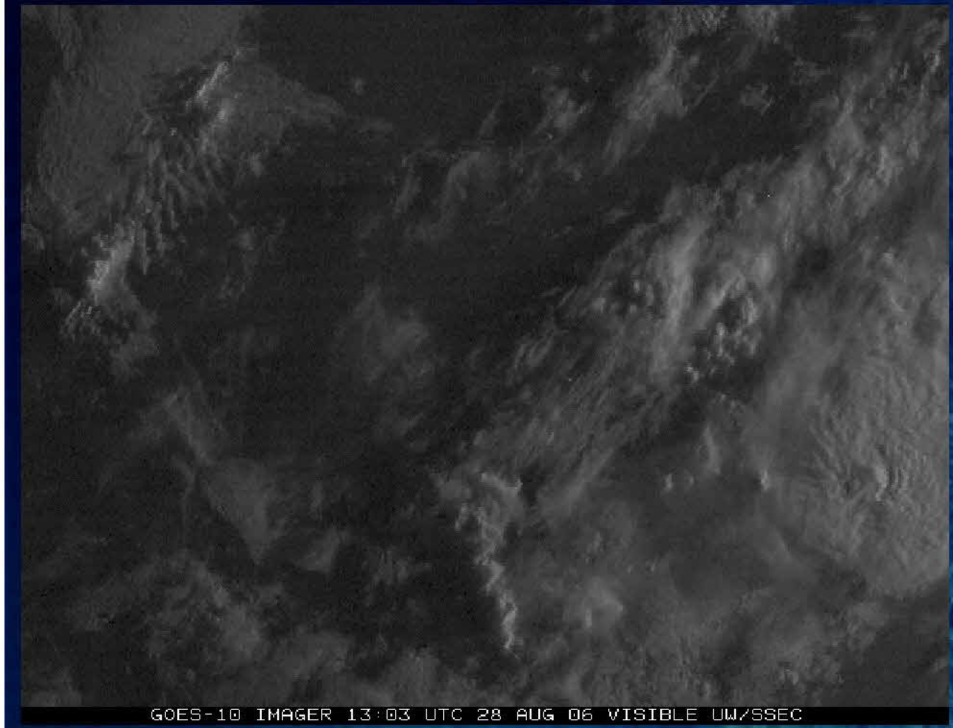
Winds derived from imagery within the overlap area of three successive orbits

Challenges

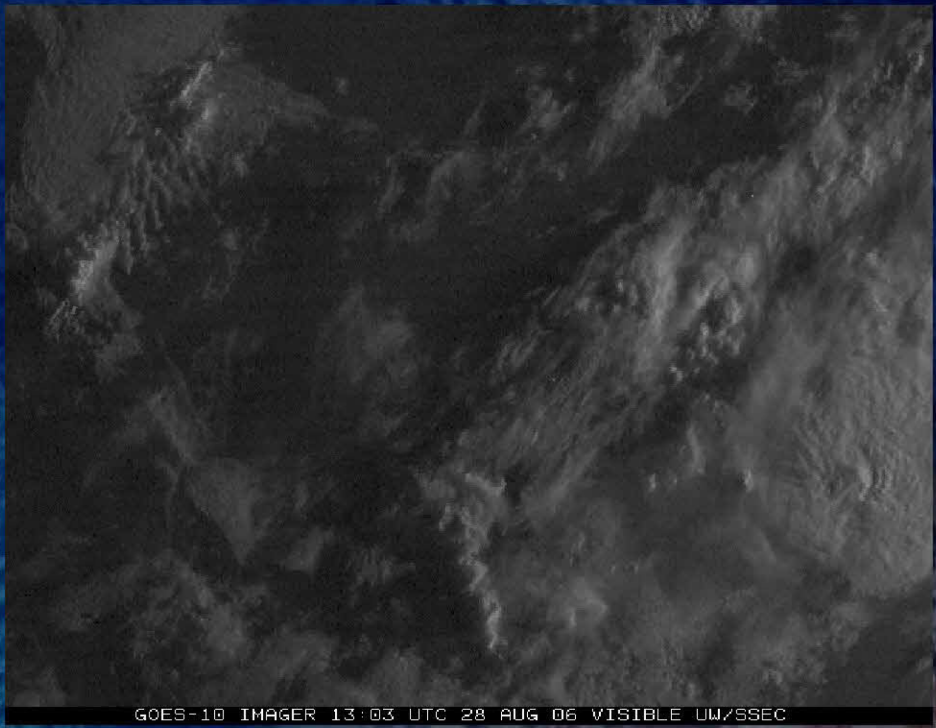
- Identifying good features to track in order to resolve atmospheric motion at desired scales (synoptic, meso)
- Tracking of potentially evolving features
- Image registration
- Height Assignment

Image Characteristics Impact on Feature Tracking

GOES-10 15-minute Imagery



GOES-10 1-minute Imagery



Spatial and temporal resolution of imagery matters... In terms of identifying features, what can be successfully tracked, and scale of motion resolved.

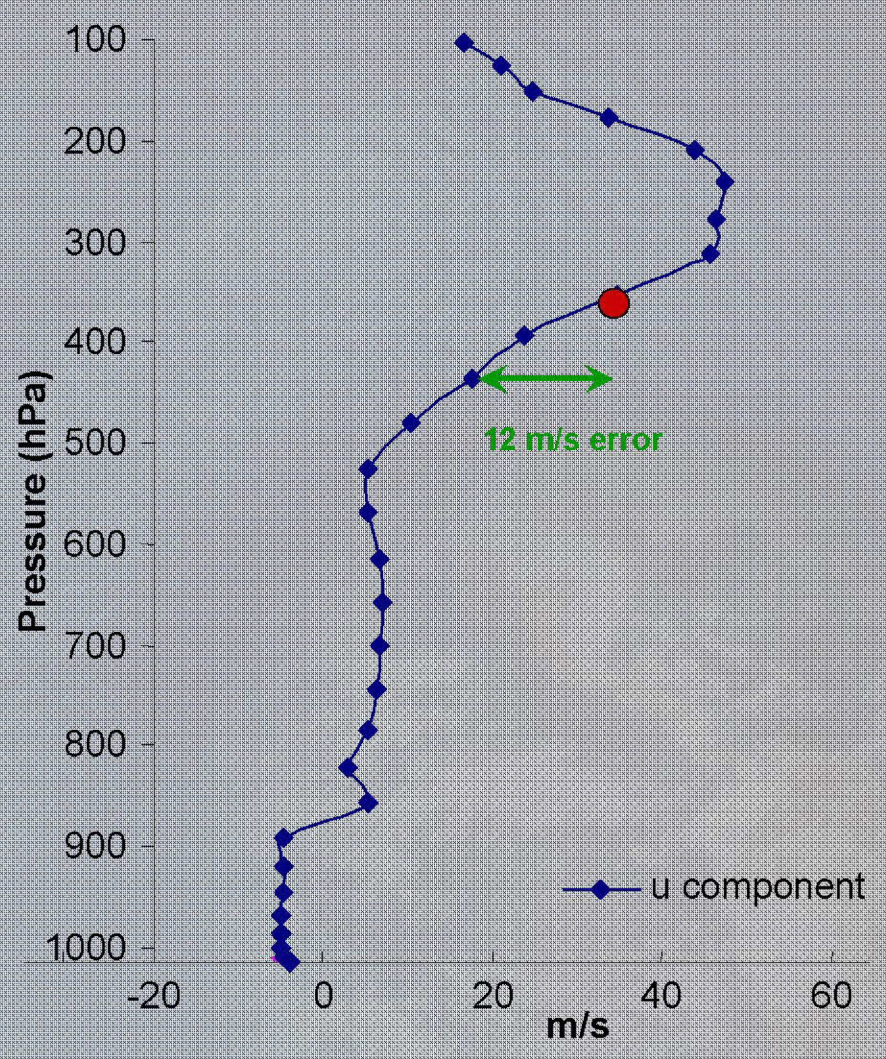
Physical Description; Image Registration Effects on Feature Tracking

Figure courtesy of S. Bachmeier, CIMSS

Good image registration is a key ingredient for the derivation of high quality satellite winds. False displacements of target tracers due to image registration errors will result in AMV errors.

Illustration of Height Assignment Error Associated with Satellite Derived Winds

- Accuracy of a satellite-derived wind is linked to the accuracy of the height assigned to it
- Height assignment errors can be especially problematic in the presence of large vertical wind shear



Preparing for the GOES-R Advanced Baseline Imager (ABI)

- Leveraging capabilities of the GOES-R ABI to help mitigate the challenges associated with deriving winds
- GOES-R ABI Satellite Wind Algorithm Development (GOES-R AWG Program)
- Future plans for Satellite-Derived Winds (PSDI and GOES-R Risk Reduction Program

Leveraging capabilities of the GOES-R ABI to Derive Improved Satellite Winds

Mitigating the challenges…

- Use of *higher spatial resolution* ABI imagery will enable identification of more suitable features to track leading to an increased number of satellite winds and better spatial coverage

- Use of *higher temporal resolution* imagery will lead to improved tracking (ie., feature evolution is minimized at smaller time intervals)

- Improved image registration with GOES-R will improve accuracy of derived winds

- Novel use of the GOES-R ABI cloud height product (2km) within the GOES-R ABI wind algorithm improves the height assigned to the derived winds.

GOES-R ABI Derived Motion Wind Algorithm Development

- Product requirements
- Algorithm overview
- Proxy data sources and sample output

GOES-R ABI Winds

Product Requirements…

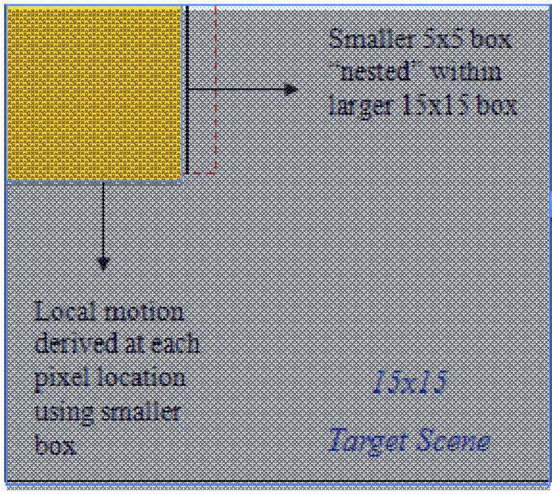
- Coverage: Full Disk, CONUS, Meso
- Horizontal Resolution: 38km
- Refresh:
  - » Full Disk: 60 minutes
  - » CONUS: 15 minutes
  - » Meso: 5 minutes

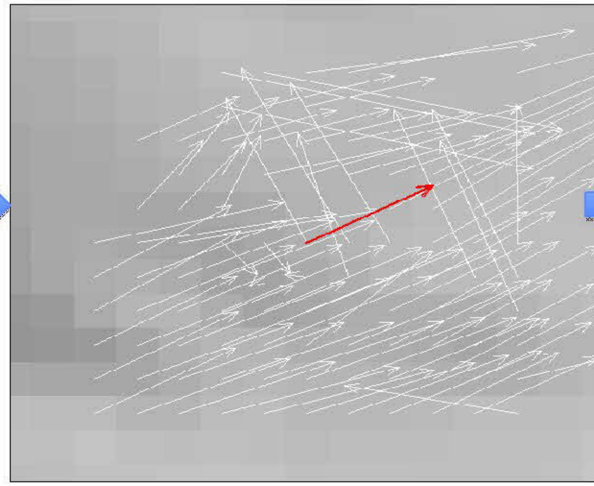
GOES-R Derived Motion Winds
Algorithm Overview…

Uses a sequence of images to arrive at an estimate of atmospheric motion for a set of targeted tracers/scenes viewed in selected spectral bands

- **Select target tracers/scenes:**
  - » Contain sufficient contrast
  - » Do not contain multi-layered clouds
- **Estimate atmospheric motion**
  - » Targeted tracers/scenes are tracked forward and backward in time using a Sum-of-Squared Differences (SSD) pattern matching algorithm
  - » When tracking cloud tracers, a nested tracking algorithm approach is used. It uses the SSD algorithm, together with a clustering algorithm, to find the dominant motion in each target scene
  - » The predecessor pixel level cloud height products are used to compute a representative height for each derived motion wind
  - » Mean vector displacement computed over the time interval of the image triplet
- **Apply quality control**

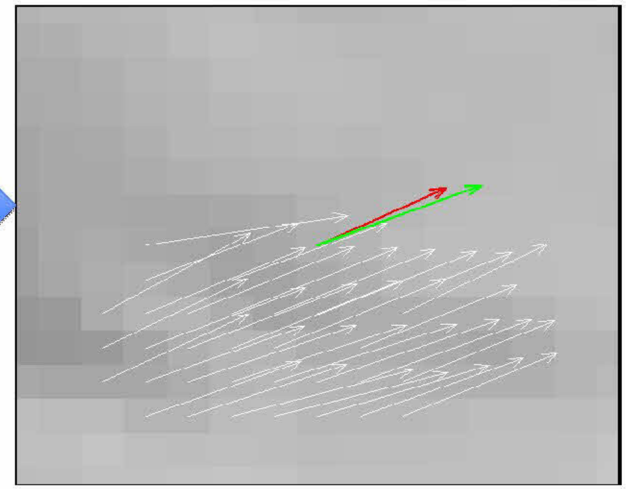
Nested Tracking Concept





Retrieved motion of larger box

Speed: 22.3 m/s



Retrieved motion of winds belonging to largest cluster

Speed: 27.6 m/s

Smaller 5x5 target scenes are nested within the larger 15x15 target scene

Retrieve local motions within larger target scene using these 5x5 scenes

Clustering algorithm used to find dominant motion in the larger target scene

Result: More representative wind is retrieved; improved accuracy

GOES-R ABI Channels to be Used to Derive Winds

Future GOES Imager (ABI) Band	Nominal Wavelength Range (µm)	Nominal Central Wavelength (µm)	Nominal Central Wavenumber (cm-1)	Nominal sub-satellite IGFOV (km)	Sample Use
1	0.45-0.49	0.47	21277	1	
2	0.59-0.69	0.64	15625	0.5	Target Selection & Tracking
3	0.846-0.885	0.865	11561	1	
4	1.371-1.386	1.378	7257	2	
5	1.58-1.64	1.61	6211	1	
6	2.225 - 2.275	2.25	4444	2	
7	3.80-4.00	3.90	2564	2	Target Selection & Tracking
8	5.77-6.6	6.19	1616	2	Target Selection & Tracking
9	6.75-7.15	6.95	1439	2	Target Selection & Tracking
10	7.24-7.44	7.34	1362	2	Target Selection & Tracking
11	8.3-8.7	8.5	1176	2	
12	9.42-9.8	9.61	1041	2	
13	10.1-10.6	10.35	966	2	
14	10.8-11.6	11.2	893	2	Target Selection & Tracking
15	11.8-12.8	12.3	813	2	
16	13.0-13.6	13.3	752	2	

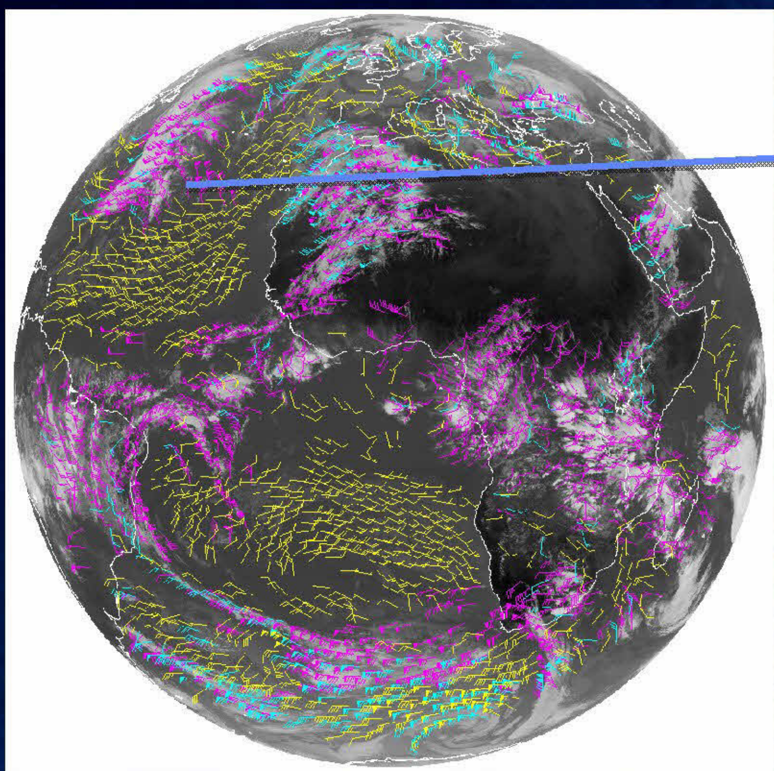
GOES-R ABI SATELLITE WINDS

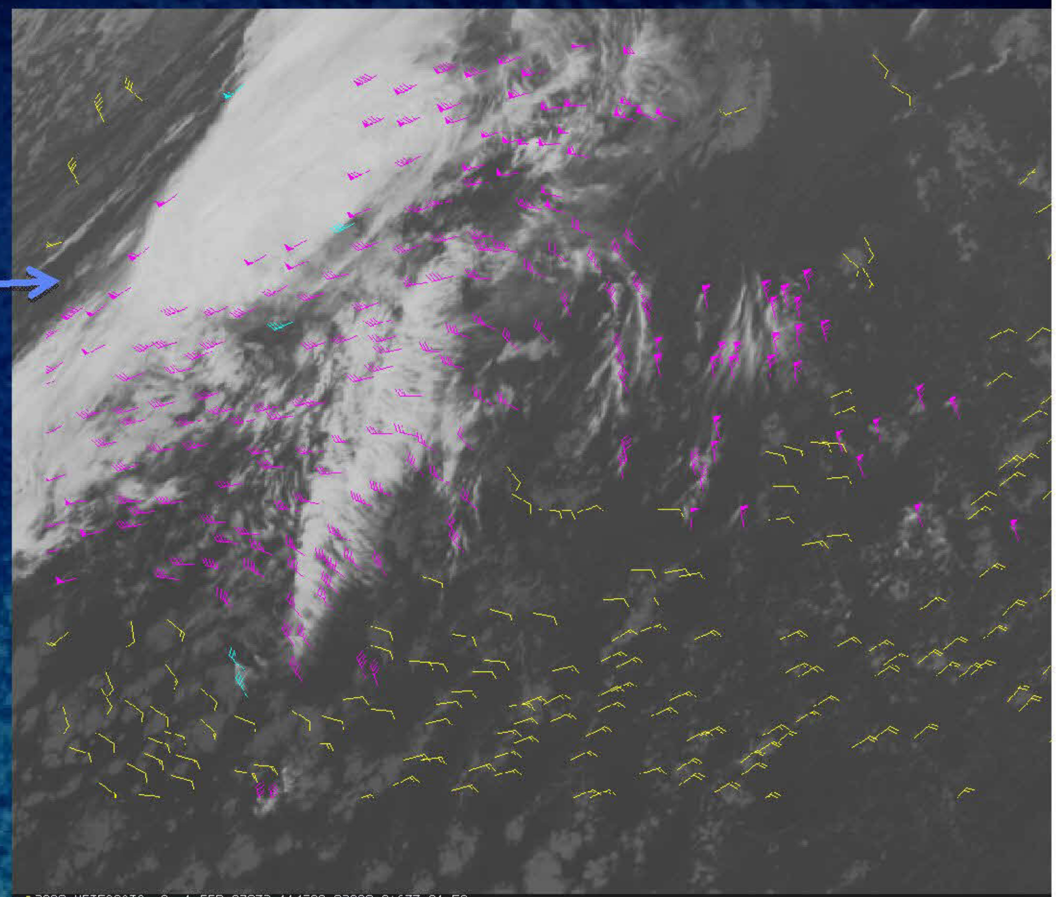
PROXY DATA SOURCES AND PRODUCT EXAMPLES

Example Output

Long-wave IR Cloud-drift Winds

Cloud-drift Winds derived from a Full Disk Meteosat-8 SEVERI 10.8 μm image triplet centered at 1200 UTC 01 February 2007





High-Level 100-400 mb

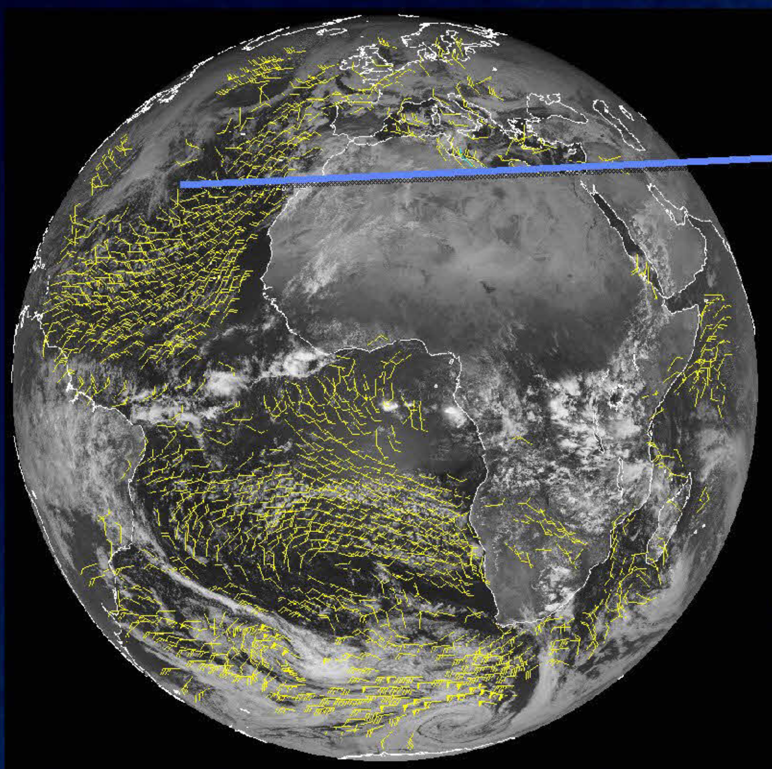
Mid-Level 400-700 mb

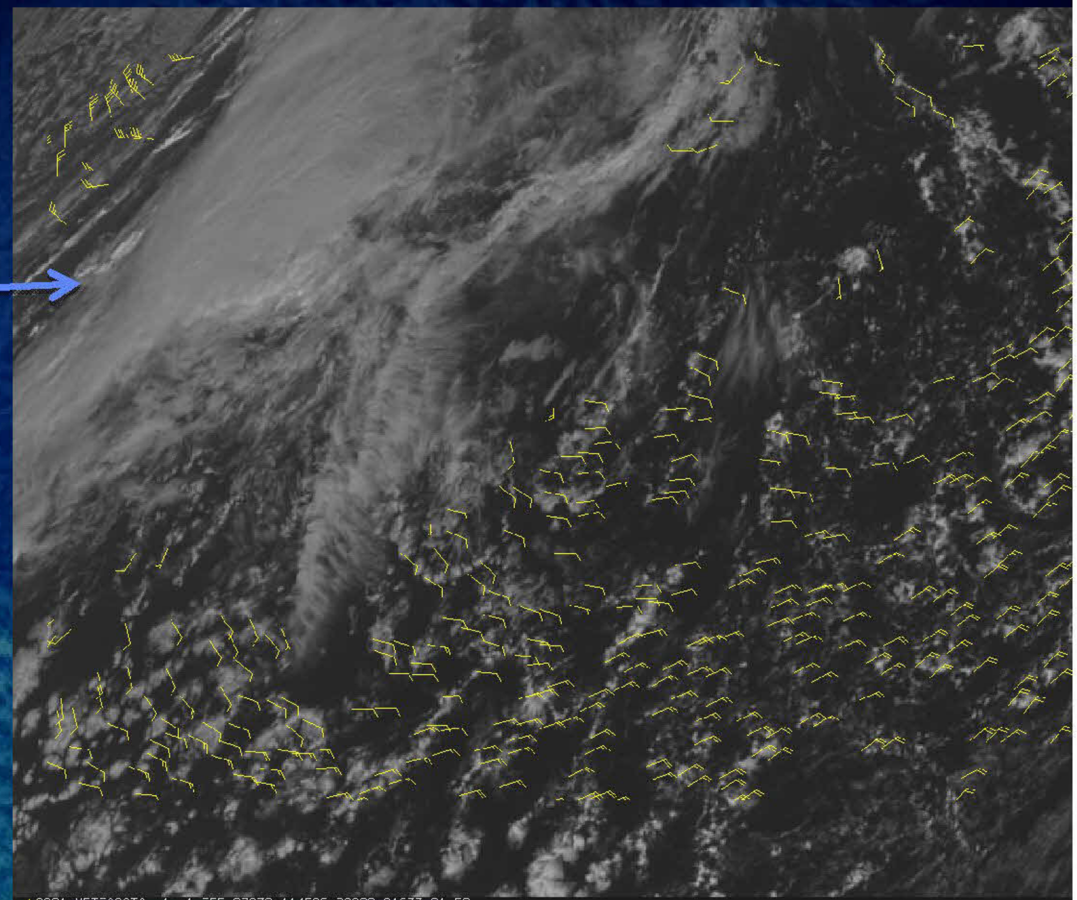
Low-Level >700 mb

Example Output

Visible Cloud-drift Winds

Cloud-drift Winds derived from a Full Disk Meteosat-8 SEVERI 0.60 um image triplet centered at 1200 UTC 01 February 2007



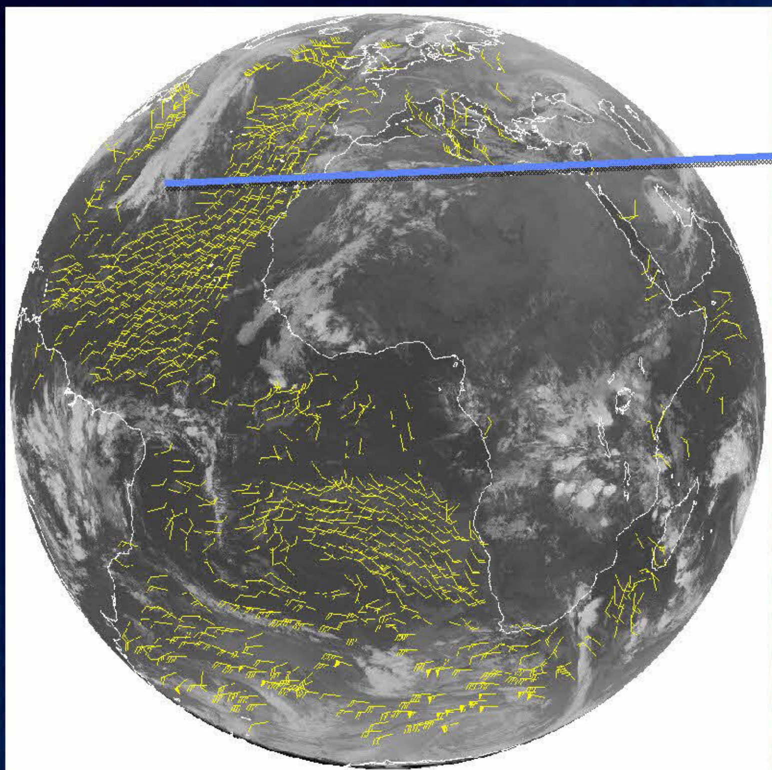


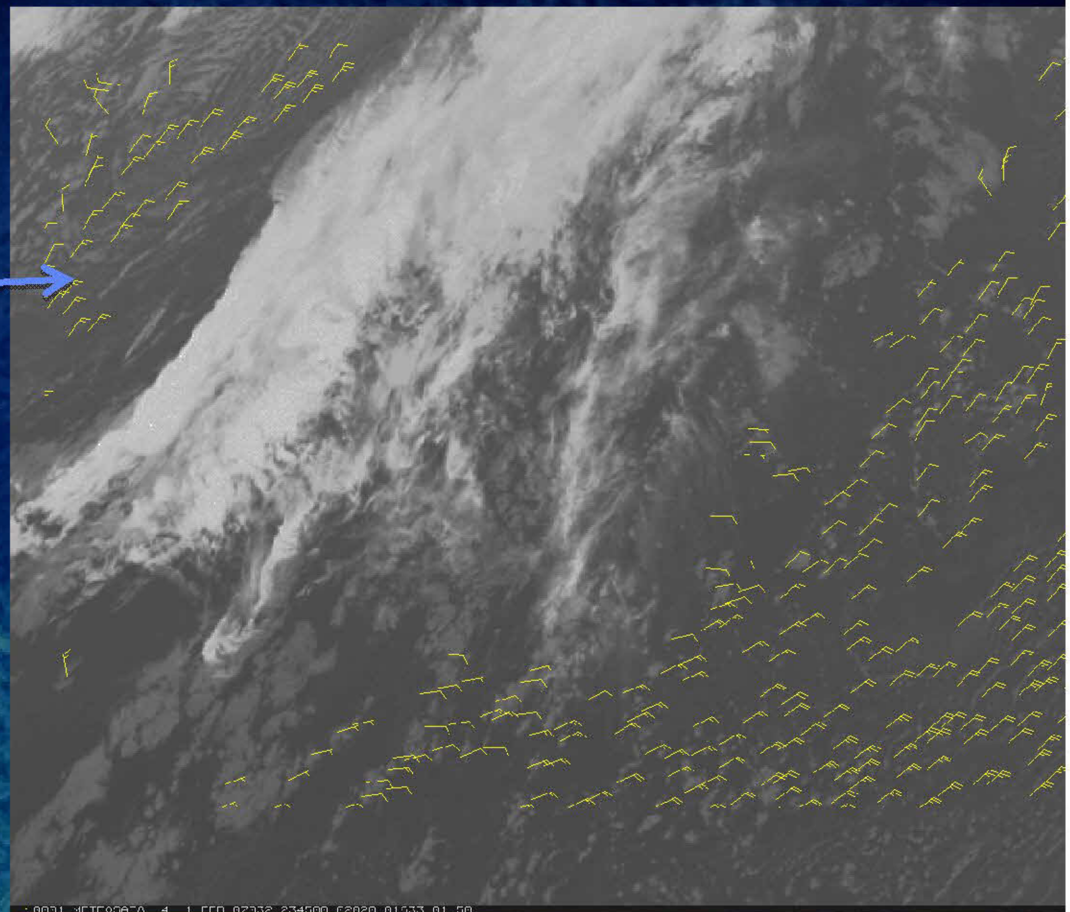
Low-Level >700 mb

Example Output

Short-wave IR Cloud-drift Winds

Cloud-drift Winds derived from a Full Disk Meteosat-8 SEVERI 3.9μm image triplet centered at 0000 UTC   02 February 2007



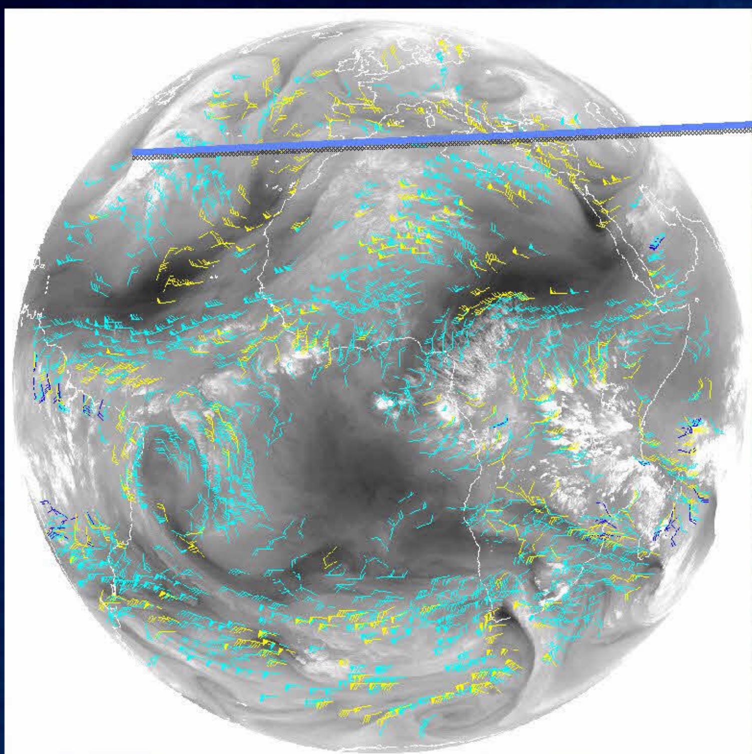


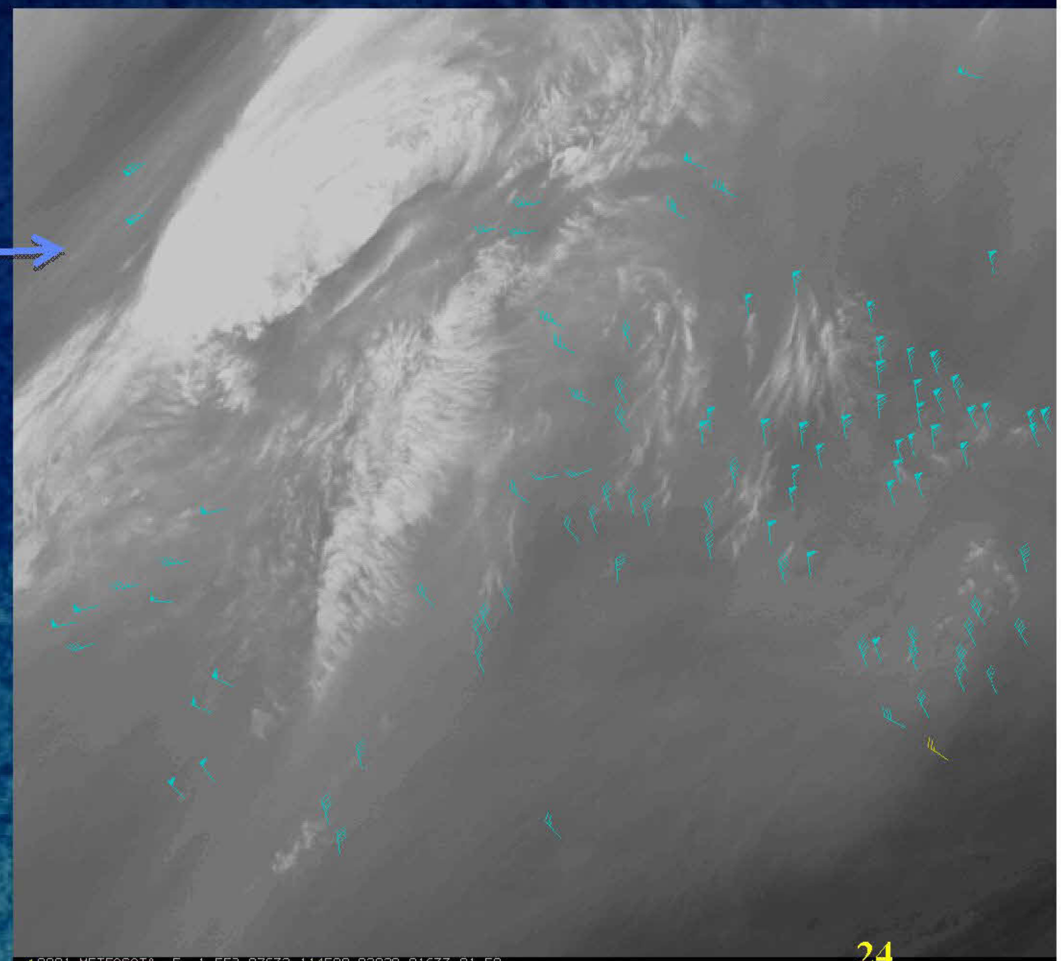
Low-Level >700 mb

Example Output

Clear-Sky Water Vapor Winds

Clear-sky Water Vapor Winds derived from Full Disk Meteosat-8 SEVERI 6.2um and 7.3um image triplets centered at 1200 UTC 01 February 2007





100-400 mb

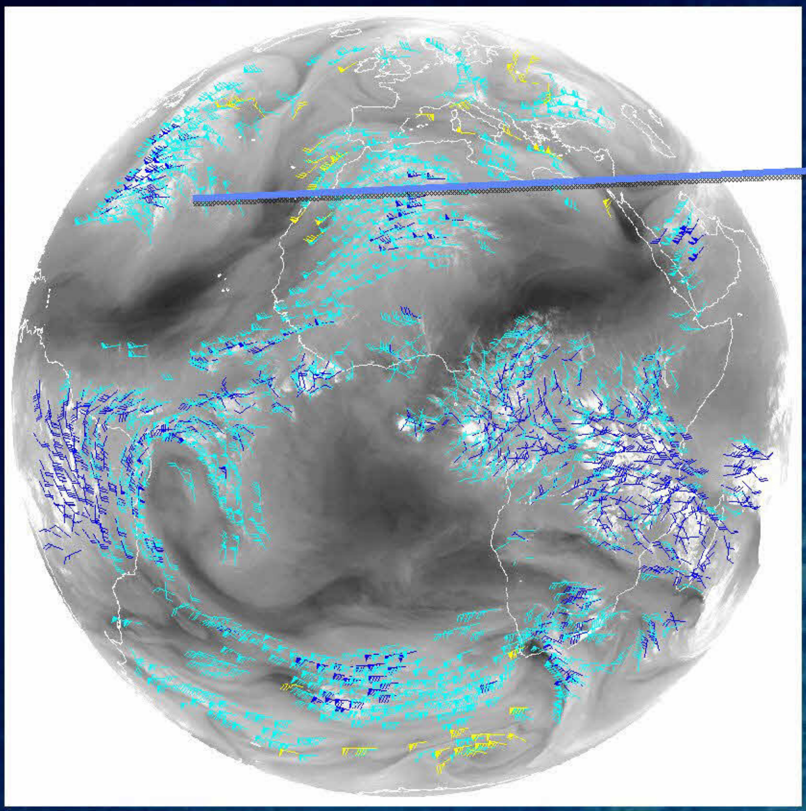
250-350 mb

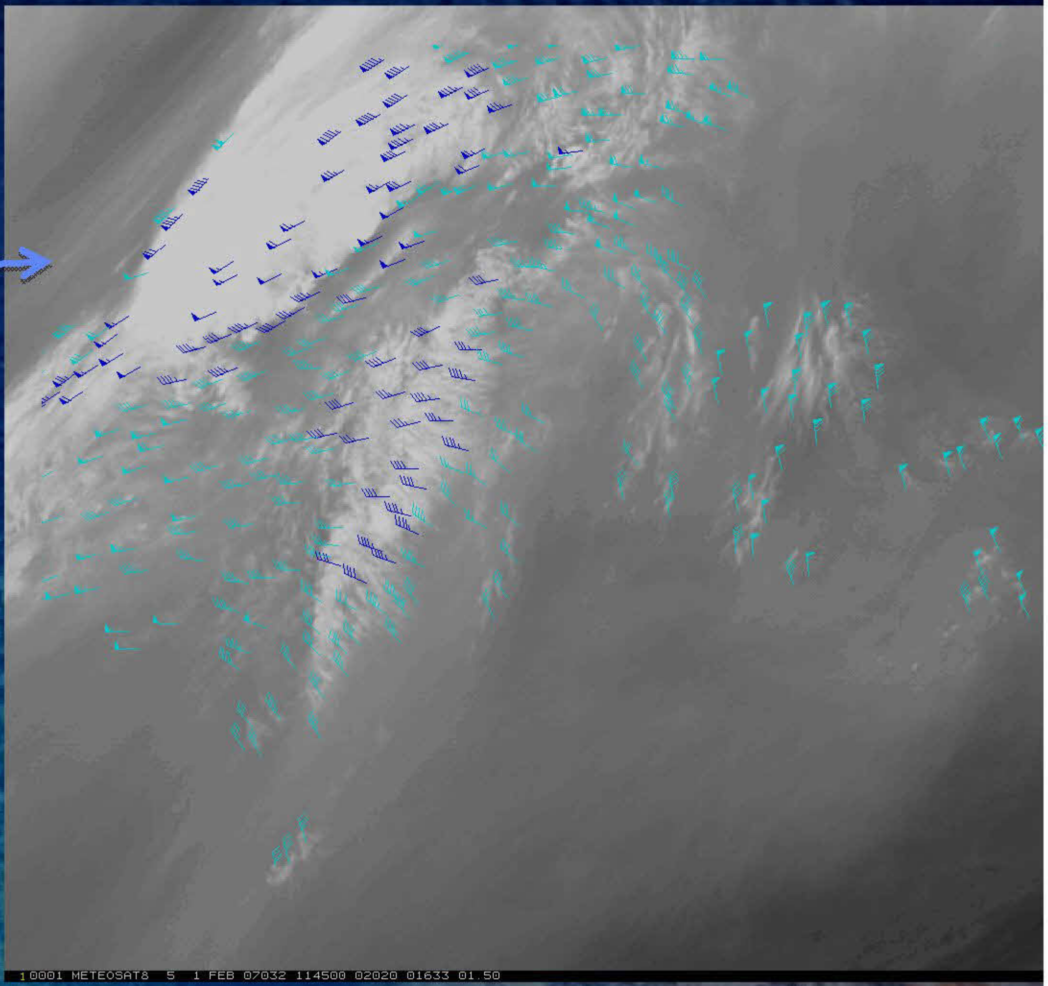
350-550 mb

Example Output

Cloud-top Water Vapor Winds

Cloud-top Water Vapor Winds derived from Full Disk Meteosat-8 SEVERI 6.2um image triplet centered at 1200 UTC 01 February 2007





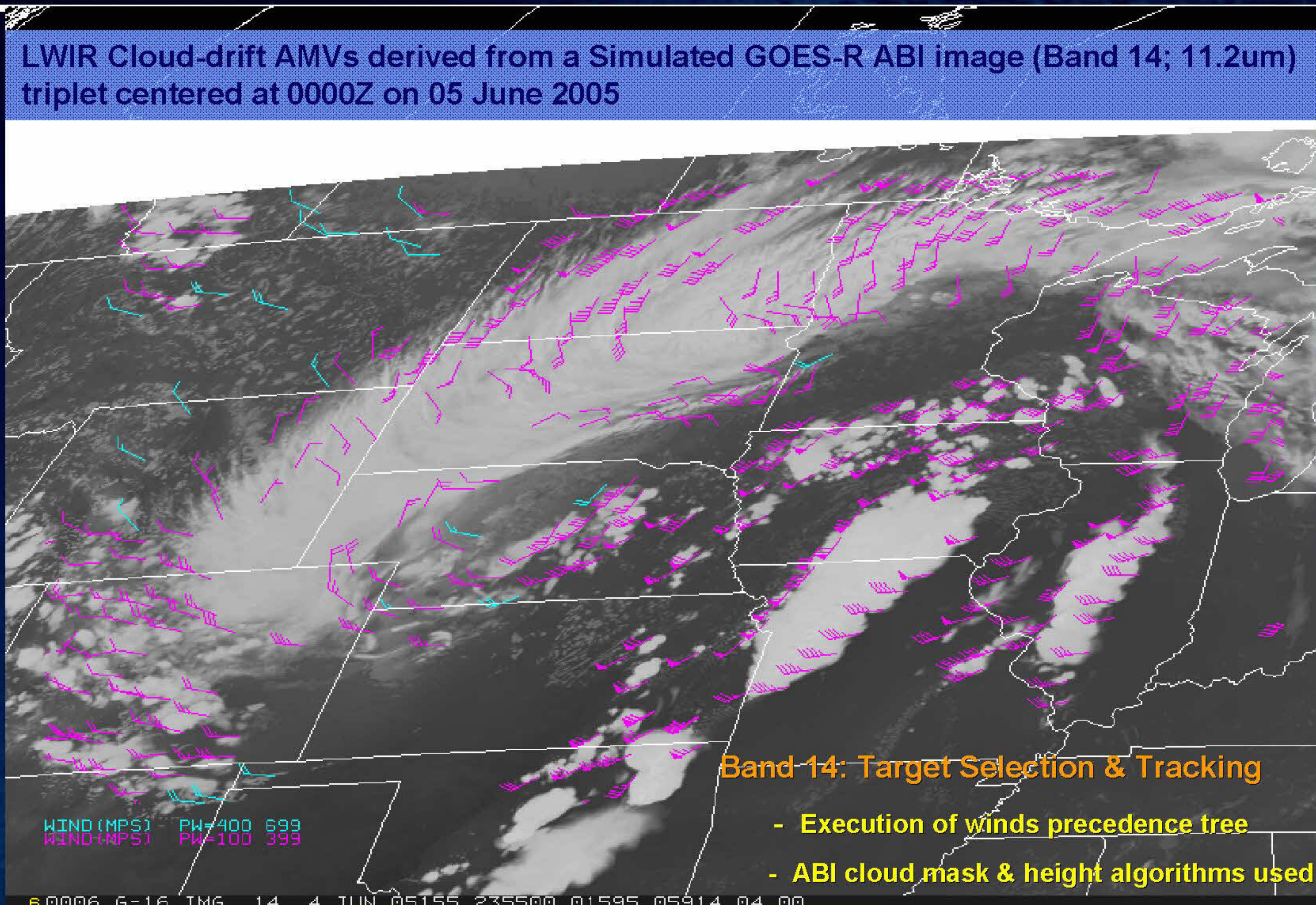
100-400 mb

250-350 mb

350-550 mb

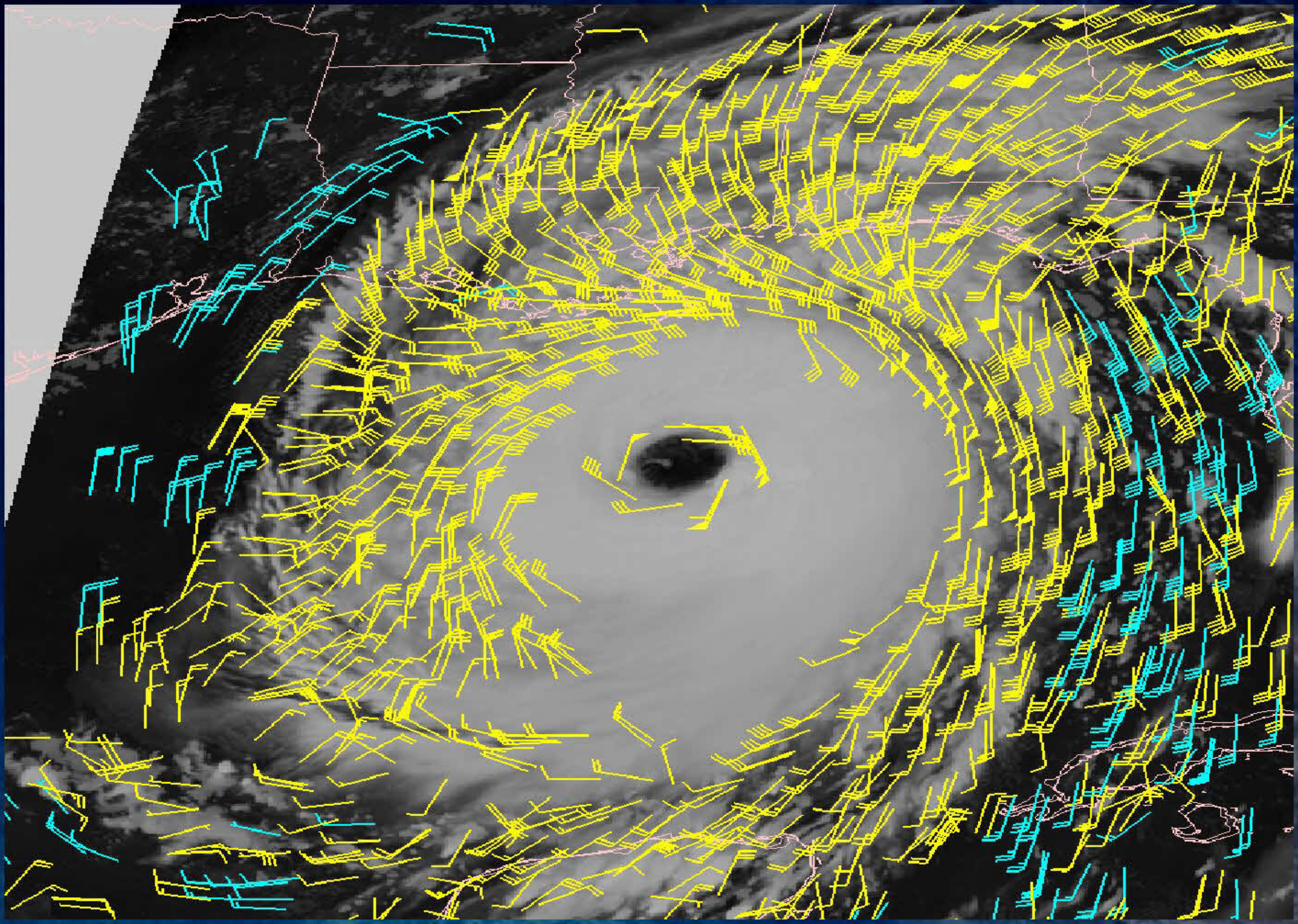
Example Output

Winds derived from simulated 11.2um imagery (2km; 5-min time step) centered over CONUS



Example Output

Winds derived from simulated 11.2um imagery (2km; 5-min time step) centered over Hurricane Katrina

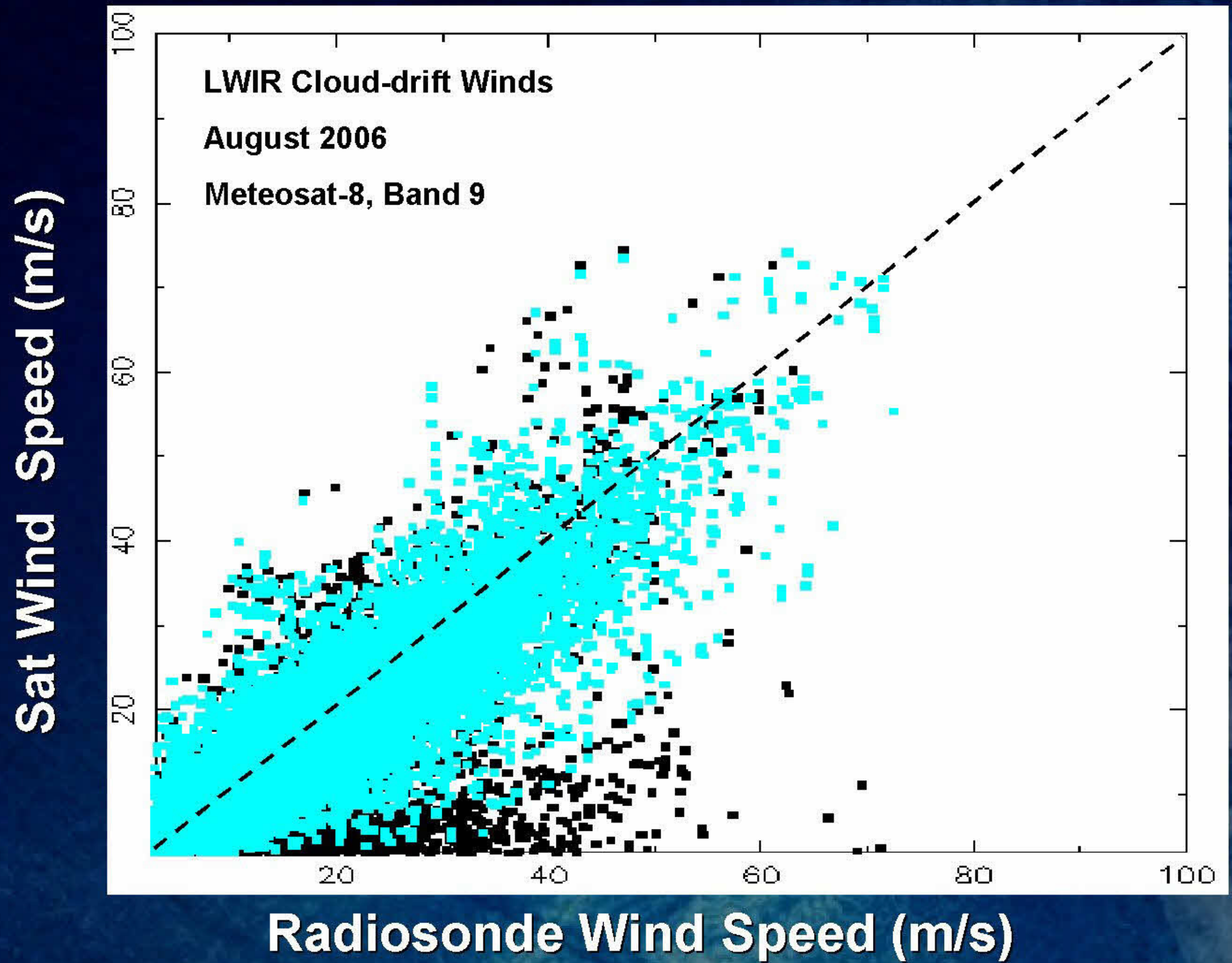


Low-mid level vectors- cyan   Upper-level vectors - yellow

Validation Results

Version 3 vs. Version 4 Performance…

Version 4 algorithm winds are better fit to radiosonde



Black – Version 3 Algorithm

RMS: 7.78 m/s

MVD: 6.14 m/s

Spd Bias: -2.00 m/s

Speed: 17.68 m/s

Sample: 17,362

Light Blue – Version 4 Algorithm (Nested Tracking)

RMS: 6.89 m/s

MVD: 5.46 m/s

Spd Bias: -0.18 m/s

Speed: 17.91 m/s

Sample: 17,428

Future Plans

- Complete delivery of the GOES-R ABI Derived Motion Winds Algorithm to the GOES-R Program (Sept 2010)

- Modify the GOES-R ABI Derived Motion Winds Algorithm for current GOES and implement it into NESDIS operations (funded via NESDIS PSDI program)

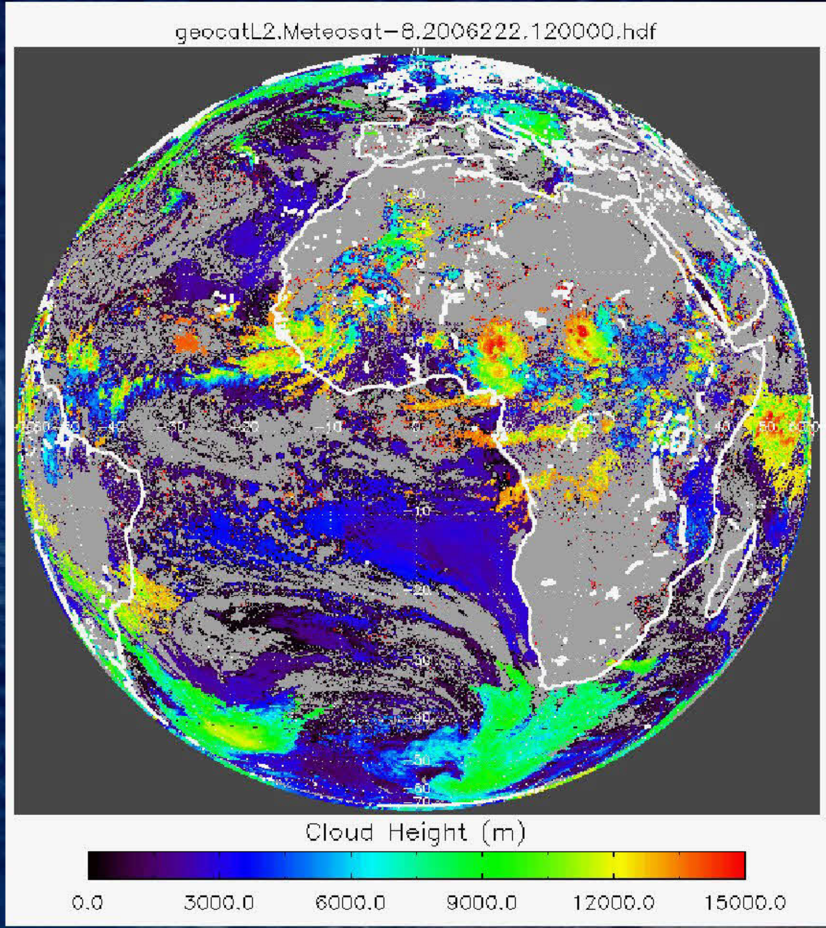
- Plan to submit two proposals to the GOES-R Risk Reduction Program
  - » To perform a NCEP GFS NWP forecast impact study using winds derived from the GOES-R winds algorithm (nested tracking)
  - » Explore opportunities to improve the nested tracking algorithm and exploit wind information associated with smaller clusters

Backup Slides

Cloud Height

- **Algorithm Highlights**
  - An optimal estimation approach is used to estimate cloud temperature, cloud emissivity and a cloud microphysical index.
  - Algorithm currently uses the 11, 12 and 13.3μm channels.
  - Cloud pressure and height are computed from NWP profiles.
  - Special processing occurs in the presence of multi-layer cloud and clouds in the presence of inversions.

- **Operational Applications**
  - Aviation Terminal Aerodrome Forecasts (TAFs)
  - Supplements Automated Surface Observing System (ASOS) with upper-level cloud information
  - Cloud initialization
  - Assimilation into mesoscale NWP models



Derived Moti

- **Algorithm Highlights**
  - Heritage in targeting, tracking, and QC algorithms lie with current NESDIS operational winds algorithms
  - Wind height assignment will rely on utilization of pixel level cloud heights generated upstream via algorithms delivered by AWG cloud application team
  - Leverages ABI's higher spatial and temporal resolution data

- **Operational Applications**
  - Weather Forecasting
  - Assimilation into mesoscale and global NWP models
  - Aviation (flight routing)